Quantitative analysis of urban sprawl in Tripoli using Pearson's Chi-Square statistics and urban expansion intensity index

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Abstract. Urban expansion is a spatial phenomenon that reflects the increased level of importance of metropolises. The remotely sensed data and GIS have been widely used to study and analyze the process of urban expansions and their patterns. The capital of Libya (Tripoli) was selected to perform this study and to examine its urban growth patterns. Four satellite imageries of the study area in different dates (1984, 1996, 2002 and 2010) were used to conduct this research. The main goal of this work is identification and analyzes the urban sprawl of Tripoli metropolitan area. Urban expansion intensity index (UEII) and degree of freedom test were used to analyze and assess urban expansions in the area of study. The results show that Tripoli has sprawled urban expansion patterns; high urban expansion intensity index; and its urban development had high degree of freedom according to its urban expansion history during the time period (1984-2010). However, the novel proposed hypothesis used for zones division resulted in very good insight understanding of urban expansion direction and the effect of the distance from central business of district (CBD).

1. Introduction

Metropolises in the world are one of human civilization aspects, their complex structures is a result of its complicated land use patterns. The urbanized land cover class changes considerably in short time as compared to other land cover classes [1]. The rapid urban land use change results in undesired urban sprawl. The urban sprawl is one of major significant problems in urban land use change and urban expansions management [2, 3]. However, the simple definition of urban sprawl is the amount of built up area and its dispersion level in the landscape [4, 5]. Furthermore, the urban sprawl level in the landscape in specific time represents the urban sprawl as a pattern. Whereas the change of urban sprawl patterns in a landscape in different time periods represents the urban sprawl as a process [5]. Nevertheless, both definitions of urban sprawl pattern and urban sprawl process can be included in one term ''urban sprawl'' [6]. In urban planning the accurate mapping of urban lands and monitoring urban expansions are significant for optimum urban analysis and planning [7]. The use of conventional urban analysis methods is really hard, time consuming, and expensive. Though, the urban expansions can be measured simply by calculating the percentage of extents covered by concrete and asphalt, i.e. impervious surfaces. Moreover, those extents which are covered by impervious surfaces are detectable and interpretable using remote sensing technique [8-11]. Hence statistical methods along with GIS and remotely sensed data can be used as efficient and cost effective option for urban growth analysis and detecting urban sprawl [5, 12, 13]. The main objectives of this work are analysis the urban expansions and their spatial patterns in Tripoli, Libya, from 1984 to 2010, by using GIS, remote sensing tools. This study employed statistical models of Pearson's Chi-Square and (UEII) analysis. Specifically, this paper identifies and assesses the urban sprawl occurrence in Tripoli and the effect of growth direction, and the distance from CBD on urban sprawl in three aspects namely; in each urban zone; in each temporal span; in overall study area.

2. Study area

Tripoli is the capital of the Libyan state, it is thousands years old. Tripoli is selected as study area in this work. It is the main financial, political, commercial, economical and business centre of Libyan state. Tripoli is located at (N 32^o 53′ and E 13^o 10′) along the Mediterranean coast in the north western part of Libya. The Tripoli urban agglomeration covers about 1143.73km^2 with population more than 1.3 million individuals.

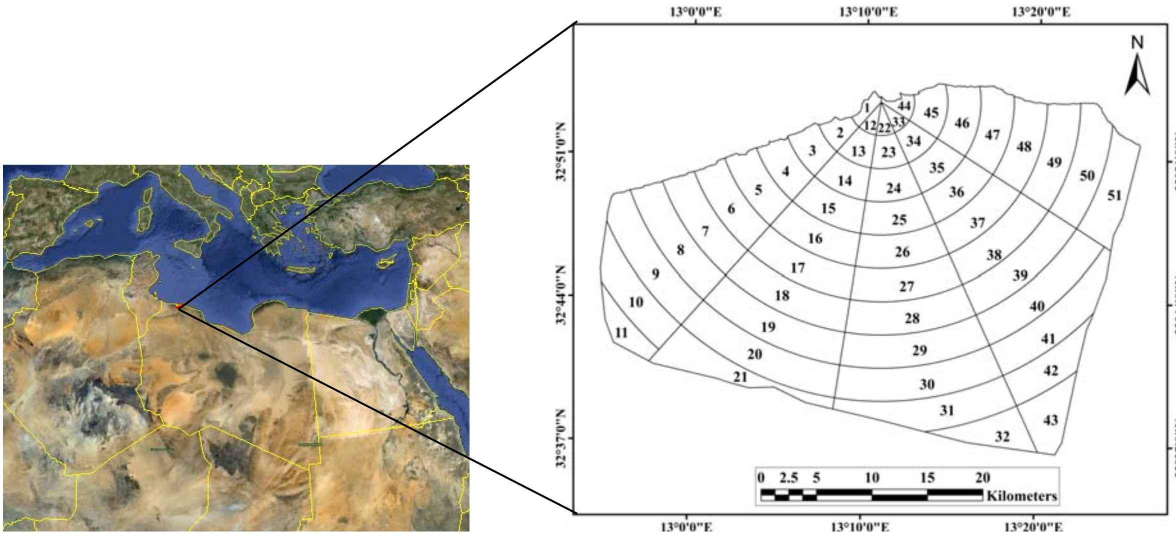

Figure1. Study area and used zones division.

3. Data used and methodology

Four remotely sensed images cover the study area of LANDSAT–TM 1984; LANDSAT–TM1996; SPOT-5 2002 and SPOT-5 2010 were classified to determine the built-up area extents of Tripoli metropolitan area. The used imageries have different spatial resolutions. A simple technique to solve this trouble is resampling the imageries which have large resolution. So that their spatial resolution equals the smallest resolution imagery. However, images resampling using bi-cubic or bi-linear resampling methods will change pixels values, i.e. average the adjacent pixel values. Resampling using nearest neighbour method will results in pixel dropout or pixel duplication. For that, imageries were used without any altering of the pixel size.

Consequently, vector map of the Tripoli metropolitan area was used for clipping used imageries. Thereafter, a supervised maximum likelihood method was used to classify all clipped images to extract the built-up areas. Since in this study only urban growth is assessed, for this reason only two classes were considered, namely: urban class and non-urban class as shown in Figure 2. Subsequently, classified imageries were clipped further by the vector map of study area which divided into 51 zones as shown in Figure 1. Then central point of Tripoli is the central business district which represents starting point of urbanization process along study area history was determined. The urban growth and built up area for all zones and for every temporal point were calculated with respective zone border by multiplying quantity of pixels in each zone by pixel size. However, the idea used in this paper based on dividing the area into five pie sections to consider and assess urban sprawl direction. Then, by further dividing the five sections into more zones to take into account of the effect of distance from central business district CBD; and to determine the sprawl in each zone. This approach will give more details about urban growth process and its patterns in whole study area and in each individual zone. Lastly, the theoretical expected and observed urban growths were calculated. Thereafter, both calculated growths were used to compute and assess the urban expansions using Pearson's chi-square technique and urban expansion intensity index.

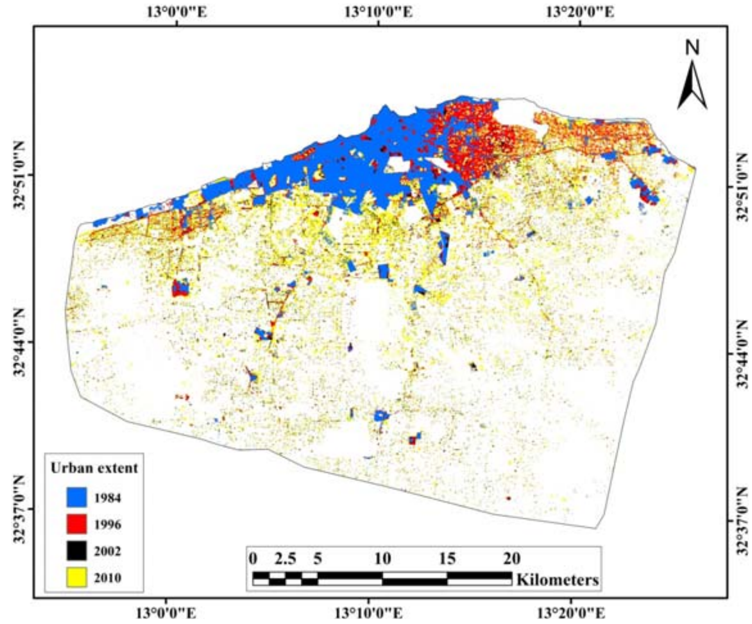

Figure 2. Urban extent in different years.

4. Results and discussions

4.1. Observed and theoretical expected built up area growth

To understand the divergence of urban growth, the observed growth should be compared with the forecasted theoretical urban growth. To calculate theoretical expected urban area growth statistically for all zones in each time period, equation 1 was used [14].

$$G_i^e = \frac{G_t^z \times G_t^t}{G} \quad (1)$$

G_i^e is expected urban growth in zone.
G_t^t is total growth in the three time periods in one zone.
G_t^z is total growth in the 51zones in one time period.
G is total growth of study area in all time periods.

Now, by subtracting theoretical expected growth from observed growth the divergence of urban growth for each zone and each temporal period can be easily identified as shown in Figure 3. Positive values confirm more growth than the anticipations, while negative values indicate less amount of growth, level of variation can also be identified by the magnitudes of differences.
The results clearly demonstrate that the observed urban expansion in several zones (especially at built up area fringes) is very much deviated from the expectations. In addition, the deviation is continuing, associating urban growth, and increasing with time. Those higher deviations reflect the freedom and independency of urban expansion; i.e. if the deviation is high means that the studied variable is independent to other similar type of variables. Based on these findings we can say there is a clear urban sprawl occurrence in most zones far from CBD of study area in all directions in time period 1996 to 2010.

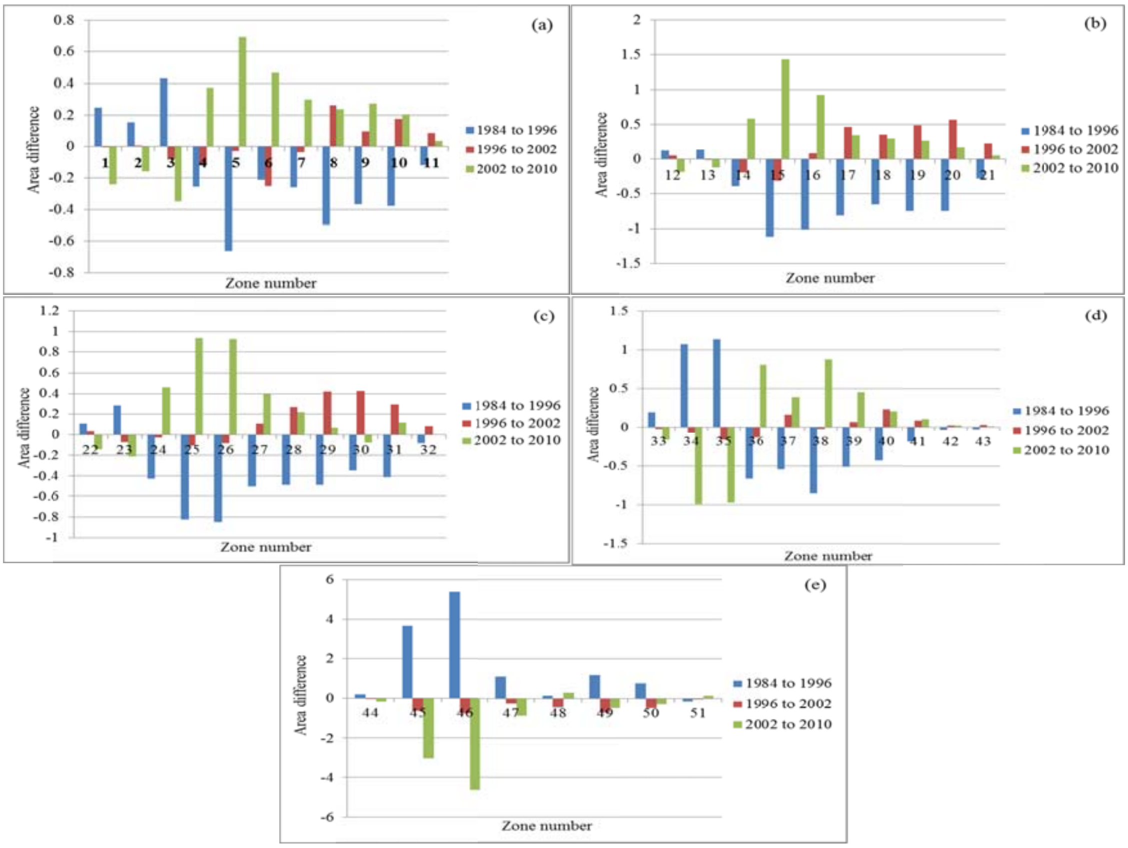

Figure 3. Difference between observed and expected built up area growth (in km^2); (a) in zones within 1st direction; (b) in zones within 2nd direction; (3) in zones within 3rd direction; (4) in zones within 4th direction; (e) in zones within 5th direction.

4.2. Degree of freedom of urban expansion

The statistics Pearson's chi square technique was used for checking the degree of freedom between pairs of variables that selected to describe the same class of land cover change [6, 14]. In this research, to find out the degree of freedom for the urban growth, Pearson's chi square analysis was carried out using following formula: $D =$ [(Observed Growth - Expected Growth)^2/ Expected Growth]. Pearson's chi square statistics estimates the freedom or degree of variation for the observed urban growth over the expected urban growth. The chi square statistics for each time period was computed using following equation 2:

$$D_i^t = \sum_i^n D_i^z \qquad (2)$$

D_i^t is degree of freedom of growth in i^{th} time period.
D_i^z is degrees of freedom of growth for i^{th} zone in same time period.

To determine the degree of freedom for each zone same formula can be used as following:

$$D_i^z = \sum_i^n D_i^t \qquad (3)$$

Moreover, the overall degree of freedom of study area can be calculated by summation of degrees of freedom of all time periods or by summation of degrees of freedom of all zones. The lower limit of chi square is 0, which means that observed growth value exactly equals the expected growth value.

Table 1 shows the degree of freedom of the three time periods which is considered very high. The overall degree of freedom of study area is 52.41 which is considered extremely high; i.e. high difference in observed and expected values. In addition, Figure 4 shows the degree of freedom in each zone specifically which is varying from zone to other. The highest degree of freedom value was recorded in zone number 46 and the lowest was in zone number 42. Generally speaking, a higher degree of freedom refers to the needs of consistency in planning, managing and controlling urban growth of the entire study area. Higher degree of freedom for a zone is a warning of unbalanced growth within the zone with the change of time. And higher degrees of freedom for a time period can be regarded as higher inter zone inconsistency in urban growth. Nonetheless, we cannot consider higher degree of freedom as sprawl, but we should consider it as disparity in urban growth.

Table 1. Degree of freedom and urban expansion intensity index of time periods

Time period	Degree of freedom (D_i^t)	UEII
1984 to 1996	10.77	0.35
1996 to 2002	5.22	0.45
2002 to 2010	36.43	1.28

4.3. Urban expansion intensity index (UEII)

In the urbanization process, due to the rule of urban deriving factors (such as road network, population density, slope, economics and so on) and their spatial impacts, the urban expansions will be different in each region and in each direction this phenomena named preference of urban growth [7]. UEII can be employed to assess and analyze the urban spatial expansion differences quantitatively. Moreover UEII can be used to recognize the preference of urban growth in a certain period [15]. The UEII reflects the probable future direction and potentials of urban expansions, and it compares the speed or intensity of urban land use change in different time periods.
The UEII standard is divided as follow: 0 to 0.28 is slow development; 0.28 to 0.59 is low-speed development; 0.59-1.05 is medium-speed development; 1.05-1.92 is high-speed development; and >1.92 is very high-speed development. The UEII for overall study area, each temporal span and each zone is calculated using formula as following:

$$UEII_{it} = \left[\frac{ULA_{i,b} - ULA_{i,a}}{t}\right] / TLA_i \times 100 \qquad (4)$$

Where, $UEII_{it}$ is the annual average urban expansion intensity index of (i^{th}) zone in time period (t); $ULA_{i,a}$ and $ULA_{i,b}$ are the quantity of built-up area at time periods a and b in (i^{th}) spatial zone respectively; and TLA_i is the total area of (i^{th}) spatial zone.

The results showed that overall study area has expansion intensity index of 0.66 which is considered moderate urban expansion speed. But on the other hand the UEII has increased dramatically from 0.35 in time period 1984-1996 to reach 1.28 in time period 2002-2010; this high increase of UEII gives an alarm of increased urban sprawl occurrence. By reading Figure 4 further one can notice that the lowest UEIIs are recorded in zones near to CBD, which means these zones relatively have stable rate of expansion. The highest UEIIs were occurred in zones that include built up area fringes, i.e. high sprawled urban expansion occurrence. However, in most urban expansion directions in the study area, the values of UEIIs are declined after exceeding the urban area fringes, i.e. low urban expansion happened.

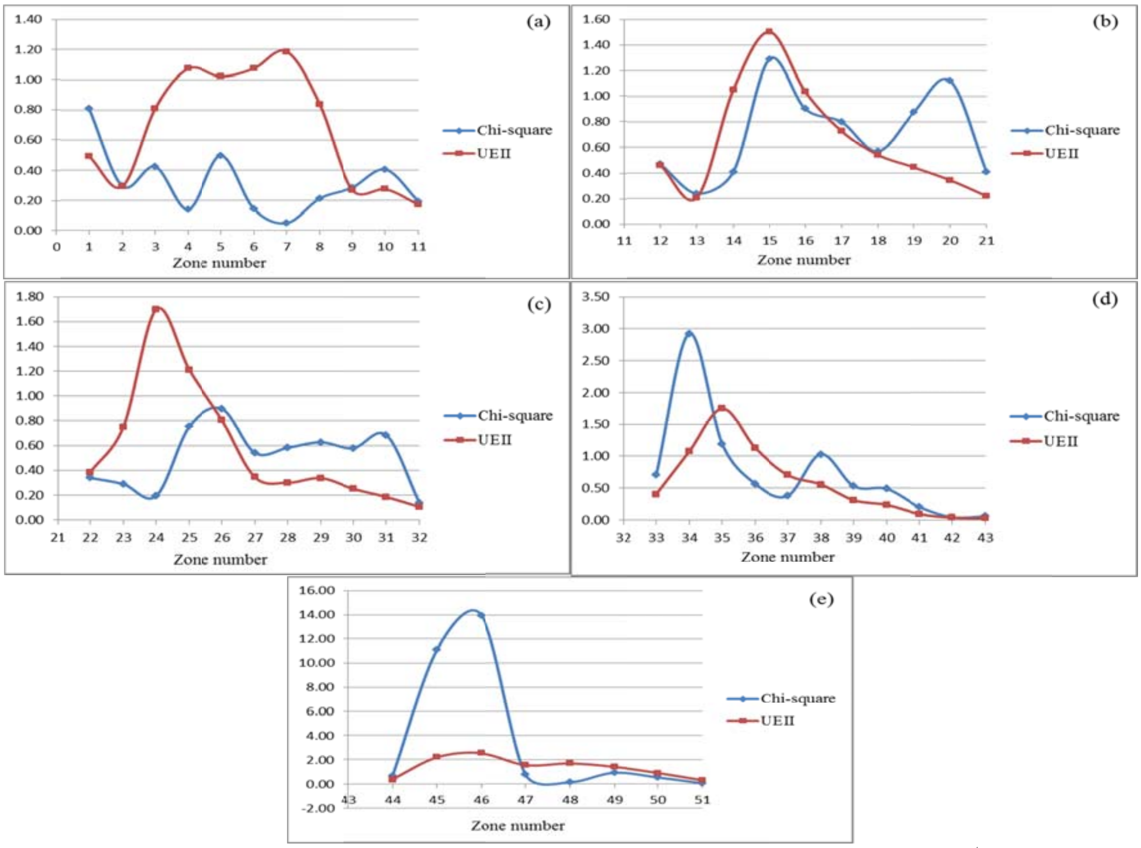

Figure 4. Variation of the two applied measures in different growth directions; (a) in 1st direction; (b) in 2nd direction; (c) in 3rd direction; (d) in 4th direction; (e) in 5th direction.

5. Conclusion

This study has investigated the urban expansion and its spatial patterns in Tripoli metropolis area from 1984 until 2010. The findings are very useful in terms of directing prospect urban plans and urbanization policies for Tripoli. The analysis results demonstrated that there is a clear signs of urban dispersion and urban sprawl for Tripoli city, i.e. sprawl is increasing with time. The techniques used in this paper can be employed to provide some guidance to recognize and assess the change likely to occur if the tendency of urban history persists. However, the proposed division technique gave very good insight into urban expansion of the study area. The expansion direction and distance to CBD which are considered in applied methods are very supportive for decision makers and urban planners. The study outcomes clearly demonstrate that Tripoli has increasing urban sprawl especially in last decade. Moreover, the observed urban expansion in most zones (especially at built up area fringes) is very much deviated from the theoretical expectations. In addition, very high sprawl was recorded at urban fringes whereas decreased sprawl was noticed in regions nearer to CBD. Finally, the sprawl level variation along all five directions offered another view of sprawl variation.

6. References

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